Maintenance

- Operating company repair and maintenance factors
- Operating company maintenance hours reports by switch type

Switching equipment

- BellCore Switching Cost Information System (SCIS) model
- Switch vendor technical descriptions
- Switch vendor price profiles
- Switch vendor equipment sizing guidelines

Economic lives

- CPUC authorized regulatory lives
- Operating company economic life studies of major investment categories

Cost of capital

- CPUC Procedures for Development of Service Costs

Lines and revenues

- Operating company annual summary accounts

Rates for telephone services

- Tariffs filed with CPUC
- Operating company reports of market trial rates

Usage statistics

- Operating company subscriber line usage studies of sample of central offices
- BellCore and AT&T studies of end-office traffic distribution
- Vendors' engineering guidelines for newly installed switches
- Operating company records of central office line fill and inward/outward movements

Common channel signaling

- Operating company filings for 800-Database service
- Operating company SS7 planning studies
- Vendor switching characteristics for SS7 services

Billing expenses

- Operating company planning studies
- Operating company customer record information systems
- Operating company billing and collection studies

Nonrecurring expenses

- Operating company studies of POTS services
- Operating company labor rates
- Operating company annual moves and changes by service

Remote switching and pair gain systems

- Operating company prove-in studies for remote switching
- Operating company outside plant investment by wire center

Interoffice transport

- Operating company interoffice unit investment studies
- Operating company and Bellcore interoffice network planning studies

Centrex

- Bellcore SCIS model
- Operating company accounts of features in use
- Operating company centrex filings

Voice mail

- Vendor technical descriptions
- Operating company planning studies

Appendix B

PAIR GAIN AND REMOTE SWITCHING

The process model described in Secs. II–V incorporates the technology most commonly encountered in expanding service in California—a copper twisted-pair local loop, digital central office switch, and fiberoptic interoffice transport. In this appendix we briefly consider alternative technologies that substitute transport resources, or switching and transport resources, for the dominant system.

PAIR GAIN SYSTEMS

Pair gain systems enable the local exchange company to provide local loops over a smaller number of cable pairs, thus "gaining pairs." In place of separate twisted copper cable pairs running from each subscriber to the central office, a pair gain system runs individual pairs from each subscriber to a neighborhood remote terminal. At the terminal each analog subscriber line signal is converted to a digital signal. Several lines are then multiplexed together and transported by a T1 digital carrier system to the central office. At the local digital switch the carrier system terminates directly onto integrated digital trunk equipment.

Several devices for multiplexing subscriber lines at the remote terminal are available, with capacities of combining 96 up to some 1500 lines. They require two to eight T1 carrier circuits, and each T1 circuit requires two cable pairs and repeater equipment every 5000 feet. The major investment components are the remote multiplexer equipment, T1 termination at the local switch, repeaters, and test equipment.

For typical subscriber loop lengths, pair gain systems are more costly than individual copper pairs for each subscriber—the fixed costs per pair gain system exceed the savings from reducing the number of cables required. Pair gain is, however, used to provide service at distances exceeding about five miles. It is also sometimes employed when an increase in service would otherwise require expanding a supporting structure to accommodate additional loops.

Only some 1.5–2 percent of Pacific Bell and GTE lines in California are supplied over pair gain systems (excluding remote switching). We have not explicitly included this technology in the local loop model.

The effect of using pair gain systems is to temper the rate at which average incremental costs increase with loop length at very large distances. Our factor for the incremental cost of loop structures indirectly includes the effect of substituting pair gain systems for structural expansion.

REMOTE SWITCHING

Remote switches are smaller digital switches that terminate subscriber lines and perform most of the functions of a central office switch for calls within the remote neighborhood. Remote switches are used to replace older central office switches that had mechanical or analog technology, to serve new lines at some distance from the central office, and to offer enhanced switching services at longer distances from the central office.

Remote switches are connected to their "host" central-office switch by digital host-remote T1 links on either fiberoptic or copper cables. The host switch provides administrative and test services for the remote unit. Calls within the neighborhood served by the remote switch (intraremote calls) are connected by that switch. Calls to other subscribers are transported to the central office switch for completion or further routing.

Serving subscribers by remote switches, rather than from the central office, has two principal effects on the estimates of average incremental costs. First, it reduces the length of the average loop for the remote subscribers. Second, it requires switching, trunk termination, and host-remote transport equipment for the traffic flowing between the remote and the host switches, and for the administrative services required for intraremote calling.

By bringing the switching point several miles closer to the remote neighborhood, remote switching reduces incremental feeder costs approximately in proportion to the change in distance. Thus the average incremental costs of access for remotely served subscribers will be considerably less than the costs of serving them with long loops from the central office.

For a remote community with calling rates equal to those of the "average" community in Sec. VI and for which 40 percent of the local calls are intraremote, we estimate that the average incremental costs per busy-hour CCS for local calls are doubled. Average incremental costs of toll calling are also increased by about the same absolute amount.

Appendix C

MODEL OF LOCAL EXCHANGE INCREMENTAL COSTS

The process model of local exchange average incremental costs has been implemented in a computer spreadsheet in a Lotus 1-2-3-compatible format. This appendix contains sample output from the model, a guide to the major sections of the spreadsheet, and a list of the cell formulas.

Figure C.1, the summary form of the spreadsheet, shows the user input parameters in the left columns and the calculated cost values to the right. This display is an abbreviated form of the full spreadsheet, shown in Figs. C.2a–C.2c. Boxes enclose the major subareas of the worksheet.

OVERVIEW OF WORKSHEET AREAS

Community Parameters (B2..C24)

These are the principal variables that characterize a model community. Growth and density ranges are designaged as 0=low, 1=medium, 2=high. "Percentage" quantities ("%") are in fact entered as decimal fractions. The model calculates the total loop length from inputs of feeder length and distribution length.

The remote switching parameter, if set (0 or 1), uses the percentage intraremote parameter to determine the volume of host-remote traffic. Percentage interoffice is the fraction of completed calls that are not terminated in the same central office. A fraction of those local calls may be tandem-switched.

Incremental costs of toll usage are calculated for a mix of toll calls based on the amount of tandem switching specified.

Investment Factors (B28..C40)

The real discount rate represents the pretax cost of equity and debt capital, net of inflation. Economic years of life for major equipment categories are used to calculate annual factors for periodic replacement.

Feeder and distribution cable "fill" and switch line utilization percentages determine effective capacities. Underground and aerial structural investment factors are applied to local loop investment to estimate incremental costs of structures.

Investment Parameters (E2..G11)

These are low and high ranges of the per unit investment cost estimates for switching (End Office and Tandem), trunk units (trunk) and interoffice and host-remote transport developed by the project from company and vendor sources.

Maintenance (E15..G24)

Low and high ranges of annual maintenance cost factors developed by the project.

Billing (E26..G28)

Estimates of the ranges of billing costs and accounting costs for a single line developed by the project.

Fixed Costs/Line (E30..G40)

Model-calculated amounts of fixed cost, per line.

Cable Investment (H2..O19)

Cells J5..L19 are per foot costs for various cable sheath sizes developed by the project. The model calculates the per line per foot costs.

Gauge (I21..J24)

Model-calculated fraction of cable that is 24 gauge, based on a uniform distribution of loop lengths between the xmin and xmax lengths.

Annual Factors (I25..N31)

Model-calculated annual factors for periodic replacement of assets at their economic lifetimes. The replacement factor is combined with the discount factor to obtain a single annualization factor that is applied to original investment.

Cable Costs by Construction Type (I32..O40)

The model itemizes cable and structural investment and maintenance for feeder and distribution cable by type of construction.

Intermediate Values per CCS (P2..R10)

Model-calculated average incremental costs per CCS carried for the functional areas of the local exchange: host-remote, intraswitch, interoffice, and tandem-switched traffic.

Costs of Local Use (P13..R25)

Estimates of Average Incremental Costs of local use, based on the usage parameters specified for the model community.

Costs of Toll Use (P27..R39)

Estimates of Average Incremental Costs of toll use, based on the tandem switching parameters specified for the model community.

Access, Switch (P36..R39)

Model estimates of Average Incremental Costs of single-line access costs at the local switch.

Average Incremental Costs (S1..U22)

Summary of Average Incremental Costs estimated by the model, for the community parameters specified. Per line incremental access costs combine investment in local loop and central office switch, associated maintenance expenses, and monthly account billing.

Estimates of Average Incremental Costs of usage are reported per originating busy-hour CCS (1.67 minutes) and per busy-hour call attempt. The estimates include switching and transport capacity and maintenance. Billing expenses for local calls assume summary monthly billing.

The access and usage costs are combined into an estimate of incremental costs for a line with the average amount of busy-hour usage.

Fixed Cost/Line (S25..U28)

Estimated fixed costs, stated per line, consist of the distribution investment, initial switch investment, and nonincremental interoffice facilities that are included in the model. Fixed costs for other local exchange facilities and overhead have not been estimated.

AIC of Toll Use (S30..U34)

Estimates of Average Incremental Costs of toll use, based on the tandem switching parameters specified for the model community. These costs are reported per originating busy-hour CCS, and per busy-hour attempt, of toll calling.

	B	C	S	T	U
1			AVERAGE INCREMENTAL COSTS		
2	COMMUNITY PARAMETERS			low	high
3	growth (0,1,2)	1	ACCESS/LINE	67	80
4	density (0,1,2)	2	loop inv	42	42
5	%ug feeder	1.00	loop maint	2	4
6	%bur. dist'n	0.00	sw inv	14	22
7	feeder len.	10000	sw maint	3	4
8	dist'n len.	2000	billing	6	9
9	[total len..]	12000			
10	lines	20000	LOC USAGE/CCS	6	11
11	orig. CCS/line	2.00	sw inv	5	10
12	attempts/line	2.10	sw+trans. maint	0.2	0.4
13	calls/month	120	interoff	0.5	0.5
14	% network	0.80	LOC USE/ATTEMPT	0.3	0.9
15					
16	remote sw.(0,1)	0	LOC USE/100 CALLS		
17	local use		billing	1.2	2.4
18	%intraremote	0.00			
19	%interoffice	0.60	AVERAGE LINE	80	106
20	tandem % of i-o	0.00	per month	7	9
21	toll use		access	67	80
22	%1 tandem	1.00	usage/line	14	26
23	%2 tandems	0.50			
24	CCS/trunk	20			
25			FIXED COSTS/LINE	69	
26			loop	60	61
27			switch	5	10
28	INVESTMENT FACTORS		interoffice	4	4
29	real disc. rate	0.15			
30	ug cable life	20	TOLL USE/CCS		
31	air. cable life	15	per CCS/yr	17	31
32	bur. cable life	20	per att/yr	0.7	1.6
33	conduit life	50	per 100 calls	0.7	1.2
34	switch eqpt. lif	17			
36	feeder fill	0.75			
37	dist'n fill	0.25			
38	ug struct. fact	0.40			
39	air struct.fact	0.20			
40	sw. line util.	0.95			
41					
	B	C	S	T	U

Fig. C.1—Summary worksheet output

	B	C	D E	F	G
1					
2	COMMUNITY PARAMETERS		INVEST. PARAMS	low	high
3	growth (0,1,2)	1	EO: per Line	80	125
4	density (0,1,2)	2	EO: per CCS	8	16
5	%ug feeder	1.00	EO: per CCS, hi	13	26
6	%bur. dist'n	0.00	EO: per ATt	1	3
7	feeder len.	10000	TAND: per CCS	3	5
8	dist'n len.	2000	TAND: per Att	1	1.5
9	[total len..]	12000	Trunk	200	350
10	lines	20000	Transport/trunk	58	58
11	orig. CCS/line	2.00	H-R Trans./trunk	45	45
12	attempts/line	2.10			
13	calls/month	120			
14	% network	0.80			
15			MAINTENANCE		
16	remote sw.(0,1)	0	ug feed/mi	1	2
17	local use		air feed/mi	6	8
18	%intraremote	0.00	bur. dist./mi	10	16
19	%interoffice	0.60	air dist./mi	6	8
20	tandem % of i-o	0.00	conduit % $	0.003	0.005
21	toll use		pole % $	0.006	0.008
22	%1 tandem	1.00	sw maint %	0.035	0.045
23	%2 tandems	.50	ckt maint %	0.015	0.025
24	CCS/trunk	20			
25			BILLING		
26			sum. bill/call	0.001	0.002
27			detail bill/call	0.007	0.012
28	INVESTMENT FACTORS		acct/line/yr	6.00	9.00
29	real disc. rate	0.15			
30	ug cable life	20	FIXED COSTS/LINE	69	75
31	air. cable life	15	loop per line	60	61
32	bur. cable life	20	sw, per line	5	10
33	conduit life	50	io, per line	4	4
34	switch eqpt. lif	17	switch	5	10
35	ckt. eqpt. life	12	get-started	1.24	3.31
36	feeder fill	0.75	engineering	3.69	6.44
37	dist'n fill	0.25	interoffice	4	4
38	ug struct. fact	0.40	at 1 end	265000	265000
39	air struct.fact	0.20	miles	8	12
40	sw. line util.	0.95	cable...	120000	180000
41					
	B	C	D E	F	G

Fig. C.2a—Worksheet

	H	I	J	K	L	M	N	O
1								
2		CABLE INVESTMENT						
3		growth	size	26g	24g	26g/ft	24g/ft	per ft
4		ug feeder						0.0141
5	0	low	600	12	15	0.0200	0.0250	0.0204
6	1	med	1800	25	30	0.0139	0.0167	0.0141
7	0	high	3000	45	55	0.0150	0.0183	0.0153
8		air feeder						0.0282
9	0	low	600	20	22	0.0333	0.0367	0.0336
10	1	med	1500	42	45	0.0280	0.0300	0.0282
11	0	high	1800	45	48	0.0250	0.0267	0.0251
12		buried dist'n						0.0452
13	0	low	100	9	10	0.0900	0.1000	0.0909
14	0	med	200	12	13	0.0600	0.0650	0.0604
15	1	high	400	18	19	0.0450	0.0475	0.0452
16		air dist'n						0.0352
17	0	low	100	6	7	0.0600	0.0700	0.0609
18	0	med	200	9	10	0.0450	0.0500	0.0454
19	1	high	400	14	15	0.0350	0.0375	0.0352
20								
21		%24gauge	0.09					
22		xmin	5000					
23		xmax	13000					
24		xhat	16800					
25		ANNUAL FACTORS				repl	maint	
26		ug				0.065	0.160	
27		air				0.140	0.171	
28		buried				0.065	0.160	
29		conduit				0.001	0.150	
30		switch				0.102	0.165	
31		circuit eqpt				0.230	0.184	
32			feeder			distribution		
33		--	ug	air	total	buried	aerial	total
34		cable ft	10000	0	10000	0	2000	2000
35		cable $	30.09	0.00	30.09	0.00	48.18	48.18
36		struct $	12.04	0.00	12.04	0.00	9.64	9.64
37		tot inv	42.13	0.00	42.13	0.00	57.81	57.81
38		maint,lo	1.93	0.00	1.93	0.00	2.33	2.33
39		maint,hi	3.85	0.00	3.85	0.00	3.11	3.11
40		tot $	44.06	0.00	44.06	0.00	60.14	60.14
41								
	H	I	J	K	L	M	N	O

Fig. C.2b—Worksheet

	P	Q	R	S	T	U
1				AVERAGE INCREMENTAL COSTS		
2	INTERMEDIATE VAL	low	high		low	high
3	PER CCS $			ACCESS/LINE	67	80
4	H-R.sw/CCS	4.63	8.43	loop inv	42	42
5	H-R.trans/CCS	0.42	0.42	loop maint	2	4
6	intra/CCS	2.15	4.30	sw inv	14	22
7	inter.sw/CCS	1.65	2.89	sw maint	3	4
8	inter.trans/CCS	0.53	0.53	billing	6	9
9	tandem.sw/CCS	3.80	6.61			
10	tand.trans/CCS	0.53	1.07	LOC USAGE/CCS	6	11
11				sw inv	5	10
12				sw+trans. maint	0.2	0.4
13	LOCAL USE			interoff	0.5	0.5
14	per orig CCS	5.03	9.66	LOC USE/ATTEMPT	0.3	0.9
15	+per CCS,if rem.	0.00	0.00			
16	sw.tot per CCS	5.03	9.66	LOC USE/100 CALLS		
17	inter per CCS	0.51	0.51	billing	1.2	2.4
18	tot per CCS	5.54	10.17			
19	maint. per CCS	0.18	0.45	AVERAGE LINE	80	106
20	+per CCS, if rem	0.00	0.00	per month	7	9
21	tot maint.	0.18	0.45	access	67	80
22	per attempt	0.30	0.89	usage/line	14	26
23	+per att,if rem.	0.00	0.00			
24	tot per att	0.30	0.89			
25	per avg. line	11.05	22.08	FIXED COST/LINE	69	75
26				loop	60	61
27	TOLL USE			switch	5	10
28	per orig CCS	16.50	29.95	interoffice	4	4
29	+per CCS,if rem	0.00	0.00			
30	tot per CCS	16.50	29.95	TOLL USE/CCS		
31	maint. per CCS	0.50	1.20	per CCS/yr	17	31
32	total/CCS	17.00	31.16	per att/yr	0.7	1.6
33	per attempt	0.74	1.56	per 100 calls	0.7	1.2
34	+per att,if rem	0.00	0.00			
35	total per att	0.74	1.56			
36	ACCESS, sw.					
37	access line	13.93	21.76			
38	maint/line	2.80	3.60			
39	tot/line	16.73	25.36			
40						
41						
	P	Q	R	S	T	U

Fig. C.2c—Worksheet

WORKSHEET CELL FORMULAS

```
B2: 'COMMUNITY PARAMETERS'
B3: 'growth (0,1,2)'
B4: 'density (0,1,2)'
B5: '%ug feeder'
B6: '%bur. dist'n'
B7: 'feeder len.'
B8: 'dist'n len'
      this value is derived:
B9: '[total len.]'
B10: 'lines'
B11: 'orig. CCS/line'
B12: 'attempts/line'
B13: 'calls/month'
B14: '% network'
B16: 'remote sw.(0,1)'
B17: 'local use'
B18: ' %intraremote'
B19: ' %interoffice'
B20: ' tandem % of i-o'
B21: 'toll use'
B22:  %1 tandem'
B23: ' %2 tandems'
B24: 'CCS/trunk'

B28: 'INVESTMENT FACTORS'
B29: 'real disc. rate'
B30: 'ug cable life'
B31: 'air. cable life'
B32: 'bur. cable life'
B33: 'conduit life'
B34: 'switch eqpt. life'
B35: 'ckt. eqpt. life'
B36: 'feeder fill'
B37: 'dist'n fill'
B38: 'ug struct. fact'
B39: 'air struct.fact'
B40: 'sw. line util.'
B42: "B"

C3: 1
```



```
C4: 2
C5: 1
C6: 0
C7: 10000
C8: 2000
C9: +$c$7+$c$8
C10: 20000
C11: 2
C12: 2.1
C13: 120
C14: .8
C16: 0
C18: .4
C19: .6
C20: 0
C22: 1
C23: .5
C24: 20

C29: .15
C30: 20
C31: 15
C32: 20
C33: 50
C34: 17
C35: 12
C36: .75
C37: .25
C38: 4
C39: .2
C40: .95
C42: "C"
D42: "D"

E2: 'INVEST. PARAMS'
E3: 'EO: per Line'
E4: 'EO: per CCS'
E5: 'EO: per CCS, hi growth'
E6: 'EO: per ATt'
E7: 'TAND: per CCS'
E8: 'TAND: per Att'
E9: 'Trunk'
E10: 'Transport/trunk'
```

```
E11: 'H-R Trans./trunk'
E15: '  MAINTENANCE'
E16: 'ug feed/mi'
E17: 'air feed/mi'
E18: 'bur. dist./mi'
E19: 'air dist./mi'
E20: 'conduit % $'
E21: 'pole % $'
E22: 'sw maint %'
E23: 'ckt maint %'
E25: '  BILLING'
E26: 'sum. bill/call'
E27: 'detail bill/call'
E28: 'acct/line/yr'
E30: 'FIXED COSTS/LINE'
E31: 'loop per line'
E32: 'sw, per line'
E33: 'io, per line'
E34: 'switch'
E35: '  get-started'
E36: '  engineering'
E37: 'interoffice'
E38: '  at 1 end'
E39:    miles'
E40: '  cable...'
E42: "E"
F2: "low"
F3: 80
F4: 8
F5: 13
F6: 1
F7: 3
F8: 1
F9: 200
F10: 58
F11: 45
F15: ''
F16: 1
F17: 6
F18: 10
F19: 6
F20: 0.003
F21: 0.006
```



```
F22: 0.035
F23: 0.015
F26: 0.001
F27: 0.007
F28: 6

      Fixed costs
F30: +f$31+f$32+f$33
      loop: distn inv + distn maint
F31: +$o$37+$o$38
F32: +f$34
F33: +f$37
F34: +f$35+f$36
      sw: getting-started inv
F35: 150000*$n$30/$c$10
      sw: engineering: 15% of inv. for avg line
F36: .15*(q$37+$c$11*q$16+$c$12*q$24)
F37: (+f$38+f$40)*$n$31/$c$10
F38: 265000
F39: 8
F40: +(+f$39/2)*30000
F42: "F"

G2: "high"
G3: 125
G4: 16
G5: 26
G6: 3
G7: 5
G8: 1.5
G9: 350
G10: 58
G11: 45
G15: ''
G16: 2
G17: 8
G18: 16
G19: 8
G20: 0.005
G21: 0.008
G22: 0.045
G23: 0.025
G26: 0.002
```

```
G27: 0.012
G28: 9
G30: +g$31+g$32+g$33
G31: +$o$37+o$39
G32: +g$34
G33: +g$37
G34: +g$35+g$36
G35: 400000*$n$30/$c$10
G36: .15*(r$37+$c$11*r$16+$c$12*r$24)
G37: (+g$38+g$40)*$n$31/$c$10
G38: 265000
G39: 12
G40: +(+g$39/2)*30000
G42: "G"
     growth index indicator = 1 for active row
H5: @if(+$c$3=0,1,0)
H6: @if(+$c$3=1,1,0)
H7: @if(+$c$3=2,1,0)
H9: @if(+$c$3=0,1,0)
H10: @if(+$c$3=1,1,0)
H11: @if(+$c$3=2,1,0)
     density index indicator = 1 for active row
H13: @if(+$c$4=0,1,0)
H14: @if(+$c$4=1,1,0)
H15: @if(+$c$4=2,1,0)
H17: @if(+$c$4=0,1,0)
H18: @if(+$c$4=1,1,0)
H19: @if(+$c$4=2,1,0)

H42: "H"
I2: 'CABLE INVESTMENT'
I3: 'growth'
I4: '  ug feeder'
I5: 'low'
I6: 'med'
I7: 'high'
I8: 'air feeder'
I9: 'low'
I10: 'med'
I11: 'high'
I12: 'buried dist'n'
I13: 'low'
I14: 'med'
I15: 'high'
I16: 'air dist'n'
I17: 'low'
I18: 'med'
I19: 'high'
I21: '%24gauge'
I22: 'xmin'
I23: 'xmax'
I24: 'xhat'
I25: 'ANNUAL FACTORS'
I26: 'ug'
I27: 'air'
I28: 'buried'
I29: 'conduit'
I30: 'switch'
I31: 'circuit eqpt'
I33: "--"
I34: 'cable ft'
I35: 'cable $'
I36: 'struct $'
I37: 'tot inv'
I38: 'maint,low'
I39: 'maint,hi'
I40: 'tot $'
I42: "I"
J3: "size"
J5: 600
J6: 1800
J7: 3000
J9: 600
J10: 1500
J11: 1800
J13: 100
J14: 200
J15: 400
J17: 100
J18: 200
J19: 400
     % 24 gauge calculation
J21: @if(+j23<j24,0,2.8*(j23-j24)*(j23-j24)/
     (j23*j23-j22*j22))minimum distance
J22: 5000
     xhat value
```

```
J23: 2*$c$9-j22
      max. distance for 26 gauge
J24: 15800

      Cable and maint costs by type of construction
      (by column)
J32: "feeder"
J33: "ug"
J34: +$c$5*$c$7
J35: +j$34*($o$4/$c$36)*$n$26
J36: @if(+$c$3=0,0,$c$38*j$35)
J37: +j35+j36
      feeder maint: low
J38: (+j$34/5280)*$f$16+@if($c$3=0,0,j$36*$f$20)
      feeder maint: hi
J39: (+j$34/5280)*$g$16+@if($c$3=0,0,j$36*$g$20)
J40: +j37+j38
J42: "J"
K3: "26g"
K5: 12
K6: 25
K7: 45
K9: 20
K10: 42
K11: 45
K13: 9
K14: 12
K15: 18
K17: 6
K18: 9
K19: 14
K26: ''
K33: "air"
K34: (1-$c$5)*$c$7
K35: +k$34*($o$8/$c$36)*$n$27
K36: @if(+$c$3=0,0,$c$39*k35)
K37: +k35+k36
K38: (+k$34/5280)*$f$17+@if($c$3=0,0,k$36*$f$21)
K39: (+k$34/5280)*$g$17+@if($c$3=0,0,k$36*$g$21)
K40: +k37+k38
K42: "K"

L3: "24g"
```



```
L5: 15
L6: 30
L7: 55
L9: 22
L10: 45
L11: 48
L13: 10
L14: 13
L15: 19
L17: 7
L18: 10
L19: 15
L33: "total"
L34: +j34+k34
L35: +j35+k35
L36: +j36+k36
L37: +l35+l36
L38: +j$38+k$38
L39: +j$39+k$39
L40: +l37+l38
L42: "L"

M3: "26g/ft"
M5: +k5/j5
M6: +k6/j6
M7: +k7/j7
M9: +k9/j9
M10: +k10/j10
M11: +k11/j11
M13: +k13/j13
M14: +k14/j14
M15: +k15/j15
M17: +k17/j17
M18: +k18/j18
M19: +k19/j19
                  Annual factors for periodic replacement
M25: 'repl.'
M26: 1/((1+$c$29)^$c30-1)
M27: 1/((1+$c$29)^$c31-1)
M28: 1/((1+$c$29)^$c32-1)
M29: 1/((1+$c$29)^$c33-1)
M30: 1/((1+$c$29)^$c34-1)
M31: 1/((1+$c$29)^$c35-1)
```

```
M32: "distribution"
M33: "buried"
M34: +$c$6*$c$8
M35: +m$34*($o$12/$c$37)*$n$28
M36: +m35*$c$38
M37: +m35+m36
M38: (+$m$34/5280)*f$18+$m$36*f$20
M39: (+$m$34/5280)*g$18+$m$36*g$20
M40: +m37+m38
M42: "M"

N3: "24g/ft"
N5: +l5/j5
N6: +l6/j6
N7: +l7/j7
N9: +l9/j9
N10: +l10/j10
N11: +l11/j11
N13: +l13/j13
N14: +l14/j14
N15: +l15/j15
N17: +l17/j17
N18: +l18/j18
N19: +l19/j19
     Annual factors - disc rate + periodic replacement
N25. comb.'
N26: +$c$29*(1+m26)
N27: +$c$29*(1+m27)
N28: +$c$29*(1+m28)
N29: +$c$29*(1+m29)
N30: +$c$29*(1+m30)
N31: +$c$29*(1+m31)
N33: "aerial"
N34: (1-$c$6)*$c$8
N35: +n$34*($o$16/$c$37)*$n$27
N36: +n35*$c$39
N37: +n35+n36
N38: (+$n$34/5280)*$f$19+$n$36*$f$21
N39: (+$n$34/5280)*$g$19+$n$36*$g$21
N40: +n37+n38
N42: "N"

O3: "per ft"
     the active growth row value:
```



```
O4: +h5*o5+h6*o6+h7*o7
     1 row for each growth level
O5: +m5*(1-$j$21)+n5*($j$21)
O6: +m6*(1-$j$21)+n6*($j$21)
O7: +m7*(1-$j$21)+n7*($j$21)
O8: +h9*o9+h10*o10+h11*o11
O9: +m9*(1-$j$21)+n9*($j$21)
O10: +m10*(1-$j$21)+n10*($j$21)
O11: +m11*(1-$j$21)+n11*($j$21)
O12: +h13*o13+h14*o14+h15*o15
O13: +m13*(1-$j$21)+n13*($j$21)
O14: +m14*(1-$j$21)+n14*($j$21)
O15: +m15*(1-$j$21)+n15*($j$21)
O16: +h17*o17+h18*o18+h19*o19
O17: +m17*(1-$j$21)+n17*($j$21)
O18: +m18*(1-$j$21)+n18*($j$21)
O19: +m19*(1-$j$21)+n19*($j$21)
O33: "total"
O34: +m34+n34
O35: +m35+n35
O36: +m36+n36
O37: +o35+o36
O38: +$m$38+$n$38
O39: +$m$39+$n$39
O40. +o37+o38
O42: "O"

P2: 'INTERMEDIATE VALUES'
P3: '   PER CCS $'
P4: 'H-R.sw/CCS'
P5: 'H-R.trans/CCS'
P6: 'intra/CCS'
P7: 'inter.sw/CCS'
P8: 'inter.trans/CCS'
P9: 'tandem.sw/CCS'
P10: 'tand.trans/CCS'
P13: '   LOCAL USE'
P14: 'per orig CCS'
P15: '+per CCS,if rem.'
P16: 'sw.tot per CCS'
P17: 'inter per CCS'
P18: 'tot per CCS'
P19: 'maint. per CCS'
```

```
P20: '+per CCS, if rem.'
P21: 'tot maint.'
P22: 'per attempt'
P23: '+per att,if rem.'
P24: 'tot per att'
P25: 'per avg. line'
P27: '  TOLL USE'
P28: 'per orig CCS'
P29: '+per CCS,if rem.'
P30: 'tot per CCS'
P31: 'maint. per CCS'
P32: 'total/CCS'
P33: 'per attempt'
P34: '+per att,if rem'
P35: 'total per att'
P36: '  ACCESS,sw.'
P37: 'access line'
P38: 'maint/line'
P39: 'tot/line'
P40: ''
P42: "P"

     INTERMEDIATE VALUES FORMULAS
Q2: "low"
     2 trunk units (H, R) + co/ccs
Q4: 2*(f$9/$c$24)*$n$30+f$4*$n$30
     HR transport
Q5: (+f$11/$c$24)*$n$31
     CO inv/ccs: hi if growing
Q6: @if(+$c$3=0,f$4,f$5)*$n$30
     interoffice: trunk units
Q7: +(+f$9/$c$24)*$n$30
     interoffice: transport
Q8: +(+f$10/$c$24)*$n$31
     tandem: 2 trunk units + tand. co/ccs
Q9: 2*(f$9/$c$24)*$n$30+f$7*$n$30
     tandem: 1 addl transport link
Q10: (+f$10/$c$24)*$n$31
     per local ccs:
Q14: 2*$c$14*q$6+2*$c$14*$c$19*(q$7)
     +$c$14*$c$19*$c$20*(q$9)
     if remote: inter-remote % * co+trans inv
Q15: @if(+$c$16=0,0,2*(1-$c$18)*(q$4+q$5))
```



```
Q16: +q$14+q$15
     interoff trans:
Q17: 2*$c$14*$c$19*(q$8)+@if($c$16=0,0,
     $c$14*$c$19*$c$20*(q$10))
Q18: +q$16+q$17
     maint:
Q19: +(2*$c$14*q$6+2*$c$14*$c$19*q$7+$c$14*$c$19*
     $c$20*q$9)*f$22
     +(2*$c$14*$c$19*q$8+$c$14*$c$19*$c$20*q$10)*f$23
     maint: remote
Q20: @if(+$c$16=0,0,2*(1-$c$18)*(q$4*f$22+q$5*f$23))
Q21: +q$19+q$20
     attempt:
Q22: (1+$c$14)*(f$6+$c$20*f$8)*$n$30
Q23: @if(+$c$16=0,0,2*(1-$c$18)*0.08*(q$4+q$5))
Q24: +q$22+q$23
     avg line (local only):
Q25: +$c$11*(q$16+q$19)+$c$12*q$22

     TOLL
     per ccs: co+trans + #tandems*(tand+trans)
Q28: 2*$c$14*(q$6+q$7+($c$22+$c$23)*(q$9+q$10))
Q29: @if(+$c$16=0,0,2*$c$14*(1-$c$18)*(q$4+q$5))
Q30: +q$28+q$29
     maint:
Q31: 2*$c$14*(q$6+($c$22+$c$23)*q$9)*f$22
    +2*$c$14*(q$7+($c$22+$c$23)*q$10)*f$23
Q32: +q30+q31
     attempt:
Q33: +(1+$c$14)*(f$6+($c$22+$c$23)*f$8)*$n$30
     rem att:
Q34: +q$23
Q35: +q$33+q$34

     ACCESS, at switch
     inv/sw fill
Q37: +$n$30*f$3/$c$40
     maint
Q38: +$f3*f$22
Q39: +q$37+q$38
Q40: ''
Q42: "Q"

R2: "high"
```

```
R4: 2*(g$9/$c$24)*$n$30+g$4*$n$30
R5: (+g$11/$c$24)*$n$31
R6: @if(+$c$3=0,g$4,g$5)*$n$30
R7: +(+g$9/$c$24)*$n$30
R8: +(+g$10/$c$24)*$n$31
R9: 2*(g$9/$c$24)*$n$30+g$7*$n$30
R10: 2*(g$10/$c$24)*$n$31
R14: 2*$c$14*r$6+2*$c$14*$c$19*(r$7)+$c$14*$c$19*$c$20*
      (r$9)
R15: @if(+$c$16=0,0,2*(1-$c$18)*(r$4+r$5))
R16: +r$14+r$15
R17: 2*$c$14*$c$19*(r$8)+@if($c$16=0,0,$c$14*$c$19*$c$20*
      (r$10))
R18: +r$16+r$17
R19: +(2*$c$14*r$6+2*$c$14*$c$19*r$7+$c$14*$c$19*
      $c$20*r$9)*g$22
     +(2*$c$14*$c$19*r$8+$c$14*$c$19*$c$20*r$10)*g$23
R20: @if(+$c$16=0,0,2*(1-$c$18)*(r$4*g$22+r$5*g$23))
R21: +r$19+r$20
R22: (1+$c$14)*(g$6+$c$20*g$8)*$n$30
R23: @if(+$c$16=0,0,2*(1-$c$18)*0.08*(r$4+r$5))
R24: +r$22+r$23
R25: +$c$11*(r$16+r$19)+$c$12*r$22
R28: 2*$c$14*(r$6+r$7+($c$22+$c$23)*(r$9+r$10))
R29: @if(+$c$16=0,0,2*$c$14*(1-$c$18)*(r$4+r$5))
R30: +r$28+r$29
R31: 2*$c$14*(r$6+($c$22+$c$23)*r$9)*g$22+2*$c$14*
      (r$7+($c$22+$c$23)*r$10)*g$23
R32: +r30+r31
R33: +(1+$c$14)*(g$6+($c$22+$c$23)*g$8)*$n$30
R34: +r$23
R35: +r$33+r$34
R37: +$n$30*g$3/$c$40
R38: +$f3*g$22
R39: +r$37+r$38
R40: ''
R42: "R"

S1: '  AVERAGE INCREMENTAL COSTS'
S3: 'ACCESS/LINE'
S4: ' loop inv'
S5: ' loop maint'
S6: ' sw inv'
```



```
S7: ' sw maint'
S8: ' billing'
S10: 'LOC USAGE/CCS'
S11: ' sw inv'
S12: ' sw+trans. maint'
S13: ' interoff'
S14: 'LOC USE/ATTEMPT'
S16: 'LOC USE/100 CALLS'
S17: ' billing'
S19: 'AVERAGE LINE'
S20: 'per month'
S21: '  access'
S22: '  usage/line'
S25: 'FIXED COST/LINE'
S26: ' loop'
S27: ' switch'
S28: ' interoffice'
S30: 'TOLL USE/CCS'
S31: '  per CCS/yr'
S32: '  per att/yr'
S33: '  per 100 calls'
S42: "S"

T2: "low"
T3: +t$4+t$5+t$6+t$7+t$8
T4: +$1$37
T5: +$1$38
T6: +q$37
T7: +q$38
T8: +f$28
T10: +t$11+t$12+t$13
T11: +q$16
T12: +q$21
T13: +q$17
T14: +q$22
T17: 100*12*f$26
T19: +t$21+t$22
T20: +t$19/12
T21: +t$3
T22: +$c$12*t$14+$c$11*t$10+($c$13/100)*t$17
T25: +t$26+t$27+t$28
T26: +f$31
T27: +f$32
```

```
T28: +f$33
T31: +q$32
T32: +q$35
T33: 100*f$27
T42: "T"

U2: "high"
U3: +u$4+u$5+u$6+u$7+u$8
U4: +$1$37
U5: +$1$39
U6: +r$37
U7: +r$38
U8: +g$28
U10: +u$11+u$12+u$13
U11: +r$16
U12: +r$21
U13: +r$17
U14: +r$22
U17: 100*12*g$26
U19: +u$21+u$22
U20: +u$19/12
U21: +u$3
U22: +$c$12*u$14+$c$11*u$10+($c$13/100)*u$17
U25: +u$26+u$27+u$28
U26: +g$31
U27: +g$32
U28: +g$33
U31: +r$32
U32: +r$35
U33: 100*g$27
U42: "U"
```

Appendix D

INCREMENTAL COST TASK FORCE MEMBERS

California Public Utilities Commission

George Cluff
Kevin Coughlan
Carl Danner
Dean Evans
Eric Jacobsen
Emily Marks
Paul Poponoe
Ernest Ting

Pacific Bell

Roger Bohl
Jack Breen
Lee Camp
Dickson Choy
Richard Collins
James Diestel
Dennis Evans
Jim Lechtenberg
Manuela McCall
Robert Meyer (University of California, Berkeley)
Tim Morris
Jerry Oliver
Carlene St. John
Marylou Shockley
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Charles West

GTE

Gerald Cohen
Lawrence P. Cole
Barry Hobbs
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NATIONAL ECONOMIC RESEARCH ASSOCIATES INC
CONSULTING ECONOMISTS

THE USE OF ECONOMETRIC ANALYSIS
IN ESTIMATING MARGINAL COST

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Presented at

Bellcore and Bell Canada Industry Forum
San Diego, California

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THE USE OF ECONOMETRIC ANALYSIS IN ESTIMATING MARGINAL COST

INTRODUCTION

Estimates of marginal cost are important in pricing telecommunications services. For example, economic efficiency dictates that prices be set as close as possible to marginal cost. Marginal cost-based pricing is particularly important in competitive markets. Pricing below marginal cost in such markets will bring charges of predatory pricing while prices set too far above marginal cost will result in uneconomic bypass. For these reasons, estimates of marginal cost should be a key focal point of rate regulation.[1]

How should marginal costs be calculated? Typically, telephone companies have used engineering models. These models describe the components of equipment needed to meet specified demands. From them, marginal costs can be derived by examining the effect of small variations in output on equipment requirements and assessing the capital and operating cost of this equipment. For example, models have been developed which describe the switching equipment needed to meet any specified level of demand. Marginal switching costs can be estimated from these models by comparing the cost of equipment needed to meet alternative levels of line and usage demand. A recent study by Bridger Mitchell describes the engineering approach to cost estimation and provides some estimates of marginal capital costs for loops and switches.

Another approach, described here, would be to estimate marginal cost econometrically. Observed data on costs incurred and outputs produced in specific locations or time periods would be used to estimate cost functions from which

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1 Many commissions have recognized the importance of marginal cost to the regulatory process. A recent decision by the Maryland PSC affirmed the efficiency gains from marginal cost pricing. There have recently been hearings on calculating marginal cost in Massachusetts, Maine, Connecticut and Delaware.

estimates of marginal costs could be derived. This approach can be useful in three ways. First, engineering models require judgment about installed capital and operating costs. These judgments are particularly difficult for estimating operating costs which may vary from time to time and from office to office. Econometric estimates could be used to test the plausibility of the assumptions used in engineering models. Second, some components of telephone cost are not easily amenable to the use of engineering models. This is true, for example, for managerial and professional overheads and marketing cost, which represent nearly 30 percent of total telephone company costs. By using observed data on overhead costs and outputs, the effect of output on these costs can be inferred. Third, the development of an efficient telecommunications system involves a host of complex and interacting decisions, many of which cannot easily be represented in an engineering model. The econometric approach, by relying on observed data to estimate marginal costs, avoids the need for engineering models.

The econometric approach is not an alternative but a supplement to engineering analysis. It can provide additional empirical evidence in support of an engineering estimate, and it can supplement the engineering analysis for some cost components. But, engineering analysis is essential to establish reasonable forms for econometric cost functions and to estimate costs for technologies not yet employed.

ALTERNATIVE ECONOMETRIC ASSESSMENTS

Econometric estimates of cost could be done at various levels of aggregation. For example, statistical analyses can and have been used to relate the costs of specific loops to loop length, loop density, and technology (copper, fiber optics, SLC). Such an approach permits a derivation of loop costs for customers of widely varying characteristics based on actual experience.[2]

Data might also be examined at the central office level. A recent study (Shin, 1987) used data on 350 central offices to relate switch and loop costs to number of access lines served, number of minutes of local and toll usage. This approach is particularly promising because there is a large base of data on costs for offices with widely varying output mixes and technologies.

While these approaches provide relatively precise estimates of component costs, to assess total marginal cost for specific services, the analysis must be done at a broader level of aggregation--a company or a subdivision of a company which operates largely autonomously. This approach permits us to capture costs which are incurred on a system-wide basis.

At the company-wide level, cost functions could be estimated using time series data, cross-section data, or both. The time series approach estimates the cost function by observing changes in output and cost for a single company over time; the cross-section approach estimates the cost function by observing differences in cost and outputs across companies at a point in time. Historically, the time series approach has predominated and has been used to assess the extent of economies of scale, to evaluate the effect on cost of technological change, and to determine the degree of substitutability between the factors of production. (For a review see Kiss, 1986.) However, time series data has not proved particularly fruitful in assessing the marginal cost of specific telephone outputs. The various outputs of interest (access lines, local and toll usage) are simply too collinear to obtain reliable estimates of marginal costs for each using time series data.

2 Such an analysis was done to estimate loop costs in recent studies for Massachusetts and New Hampshire. For the Massachusetts study, see DPUC Docket 1731.

Moreover, changes since divestiture may make it difficult to rely upon time series data to estimate cost conditions prevailing today.

CROSS COMPANY STATISTICAL COMPARISON

Here we explore the use of cross-section data to estimate marginal cost at the company-wide level. The use of such data avoids the problems of collinearity observed in time series data and permits us to focus on the post-divestiture period. The basic data set consists of information on 39 companies observed over the four years 1984-1987 (24 Bell and 15 non-Bell companies).[3] For these companies, we related total cost to three major components of output (access lines, local usage, and toll usage) and a measure of the technological mix of the capital stock (percentage of lines served by electronic switching). Statistical analysis was used to estimate the parameters of several alternative cost functions from which we have derived estimates of marginal cost.

The cost measure used in this study is somewhat different from the accounting costs typically reported in annual reports and in reports to the FCC. Although current operating expenses are measured in the same way as they are in accounting reports, capital costs reflect annual cost of using capital which is revalued every year to reflect its replacement value. The replacement value of the capital stock was estimated by determining the distribution of the current capital stock by vintage. The replacement value of these investments was derived by escalating original costs to reflect changes in the price of telephone equipment over this period and reducing the value to reflect the effects of depreciation. Equipment was escalated in value using the telephone plant index published in Bell System Statistical Manual prior to divestiture and available for individual companies after

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[3] In this context, Southern New England and Cincinnati Bell are treated as Bell companies.

divestiture. Annual depreciation was estimated at the current average rate observed for each company in the sample (from FCC Form M). The <u>annual</u> cost of this capital stock includes interest, return, and the net effect of physical depreciation and equipment revaluation.

ESTIMATION METHODS

Two alternative cost functions have been examined in this paper. In the first, cost is a linear additive function of three outputs--access lines, minutes of local usage and minutes of toll usage. In the second, local and toll calls are substituted for minutes of use as the determinants of cost. In both functions, to take account of the effect of technology on costs, we allow the coefficient relating local and toll calls (or minutes) to cost to vary linearly with the percentage of switches which are electronic. For the minute equation, the precise form is:

Cost = a + b*lines + c*local minutes + d*toll minutes +
e*electronic minutes + f* Bell lines

We did not include an interaction between line costs and percent electronic because electronic switching is generally thought to have a greater effect on usage than on line cost and there was too much collinearity to include both line and usage effects in the same model.

This linear additive cost function assumes that each of the outputs requires specific <u>separable</u> capital investments, that the marginal cost of these outputs is unaffected either by the level or mix of outputs being produced, and that each output is produced with fixed proportions of labor, capital and materials. The function allows for scale economies only insofar as there may be fixed cost to operate a phone company which is independent of the output level. While restrictive, these assumptions do not seem unreasonable or inconsistent with engineering analysis of marginal cost. The capital investment needed to produce access and usage includes local loops (connecting customers to the central office) switching equipment and interoffice equipment In engineering analyses of costs, it is common to view loop costs as an approximately linear function of the number of customers served, switching costs as separable into components driven by lines and by peak usage and interoffice cost as an approximately linear function of peak interoffice usage. Moreover, for a specific type of technology most engineering analyses assume that operating costs are a fixed proportion of capital investment If this is an accurate view, the linear additive function is appropriate.

Two statistical approaches were used to estimate the parameters of these cost functions. In the first case, cost and output data for each of the years 1984 through 1987 were averaged to produce 37 to 39 observations and these average cost and output data were related using ordinary least squares regression.[4] Data were averaged over these four years to eliminate random temporal variations and hence improve the precision of the estimate.

In the second case, we created a data sample consisting of each company observed in each year (a total of 142 to 151 observations) and a random effects model (see Hausman and Taylor, 1980) was used to estimate the relationship between output and cost for those data. The random effects model assumes that the error term in these panel data consist of two components: one which varies both over time and company and another error which is specific to each company but does not vary over time. The random effects model takes this error structure into account in estimating the parameters of these functions.[5]

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4 For the calls data, we had 37 and for the usage data 39 observations.

5 In each case, the random effects model passed both a Lagrange multiplier and Hausman test. The Lagrange multiplier test (Breusch and Pagan, 1979) determines whether the random effects model improves upon the OLS model through correction of heteroskedasticity over the cross-sections. The Hausman test (cf. Hausman, 1978) compares the random effects model with the fixed

MARGINAL COST ESTIMATES

The estimated parameters of the linear cost functions are summarized in Table 1. Several results are immediately apparent. The cost equations account for over 99 percent of the intercompany variation in cost and all of the variables in these equations are significant at the 99 percent level or higher. This suggests that variations in output and technology account for most of the variation in cost across companies, and the effects of outputs and technology on cost are measured with substantial precision from these data. Second, since the intercept term is close to zero (the constant term is typically 5 percent or less of average cost), the equations exhibit approximately constant returns to scale. Finally, the use of electronic switches markedly reduces cost. Electronic local usage is 9 to 48 percent of the costs of electromechanical calls, depending upon which function is used. For toll calls, electronic switching lowers costs by 50 percent. Thus, whereas total costs for the average company was $1.6 billion, annual costs for an all electronic system would be $1.2 to $1.5 billion or 20 to 30 percent lower.

Table 2 summarizes the estimates of marginal cost derived from these equations. For comparability the marginal cost from the call model has been expressed on a per minute basis by dividing the marginal cost per call by the average number of minutes per call.[6] Marginal costs are derived separately for calls served by electronic and electromechanical switching.

Using exclusively cross-section data and the minutes of use model, marginal cost is $31 per access line per month, 2 cents per minute for electronic

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effects model; in passing the Hausman test, we may conclude that the parsimony of the random effects model still provides a consistent estimate.

6 The calls data used here measure the number of originating calls. For the minute data, interoffice calls are measured both at the originating and the terminating switch. Consequently, a 4 minute call will generate 8 minutes of measured usage--4 at the originating and 4 at the terminating switch.

and 2.1 cents per minute for electromechanical local usage. Marginal cost for toll usage is 3.9 cents per minute for electromechanical and 2.0 cents per minute for electronic usage.

When usage is measured by number of calls, the marginal cost of access is lower ($20.94 per month), costs for local usage are higher (3.8 cents per minute for electromechanical and 0.9 cents for electronic switching), while toll usage costs are lower (2.9 cents for electromechanical and 1.4 cents for electronic switches).[7]

When panel instead of cross-section data are used, there are two principal differences. First, access costs are $25 per line in both the minutes and calls models. Second, electronic switching reduces usage cost much less in the panel than in the cross-section data. Electronic local usage costs, which were only 10 percent to 25 percent of electromechanical costs using cross-section data, are 50 percent as large using panel data. This may be because the panel data averages the effect of variations in technology on cost measured cross sectionally and over time. The time period data may reflect the short-term consequences of increasing the percentage electronic which might be expected to be less than the longer term effect observed in the cross-section.

The difference in results between the call and minutes equation have an interesting interpretation. The minute equations results in much lower marginal cost per minute than those based on calls data. This is because, in these data, holding time is either unrelated or inversely related to cost. While this seems counter-intuitive, there may be a simple explanation. For areas with relatively short calls, a larger proportion of calls may be made in the peak period. For

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[7] As measured here, the marginal cost of usage reflects the added cost per <u>average</u> minute of added usage. In reality, of course, only busy hour usage affects costs, and this study assumes the same ratio of costs to busy hour usage in each company.